Identificação e mapeamento de amostras de solo na vizinhança da Mina da Panasqueira, de acordo com os efeitos nocivos para a saúde humana

Splitting and mapping soil samples in the vicinity of Panasqueira Mine according to harmful effects on human health

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Abstract

Mining activity is one of the industrial activities that produce more residues, most of then left in piles or tailings dam, subject to weathering, which leads to the production of acid mine drainage that consequently affects the surrounding environment (namely in soils) and the population living in the area.

The beneficiation process at Panasqueira Mine have given rise, during a long production period, to a large amount of sulphide-rich waste, contained in several tailing ponds, two of them located nearby a small village – S. Francisco de Assis Village. The community living in there subsists, not only from the mining activity, but also from agriculture and cattle breading.

When soil quality became compromised affects all the chain, from the soil itself, prone to be absorbed and/or ingested; to plants, that apart from nutrients also capture heavy metals; to cattle fed locally until the population that consumes vegetables and meat from local production. The assessment of soil contamination in this area is then of most importance.

A new methodology for soil sample categorisation according to harmful effects on human health is proposed, based on Multivariate Data Analysis. The combining use of Principal Component Analysis (PCA) and Correspondence Analysis (CA) allowed the identification of the contaminant group of chemical elements that act in the Panasqueira mining area. Once identified this group was possible, through Correspondence Analysis, to rank samples according to their potential contaminant effect, previously established by literature reference guide values. Once identified, the samples can be mapped permitting the geographical recognition of clean, in need of intervention and reclamation areas.

Keywords: Mining areas, Soil pollution, Principal Component Analysis, Correspondence Analysis

Resumo

A actividade mineira é uma das actividades industriais que mais resíduos produz, sendo que a maioria é depositada em escombreiras e barragens de lamas, sujeitas à acção da chuva e do vento, produzindo lexiviação e consequentemente drenagem ácida, a qual afecta todo o ambiente envolvente (com especial atenção para os solos) e a população residente na área.

A actividade mineira na Mina da Panaqueira tem originado, durante um longo período de produção, uma quantidade apreciável de resíduos enriquecidos em sulfuretos e metais pesados, os quais foram acondicionados em várias escombreiras e barragens de lamas, duas delas localizadas muito perto de uma pequena vila – a Vila de S. Francisco de Assis. A comunidade ali residente tem como meio de subsistência, para além da mina, a agricultura e a pecuária.

Quando a qualidade do solo é comprometida toda uma cadeia é afectada, desde o solo em si à população, passando pelas plantas e pelos animais. A avaliação da contaminação do solo nesta área revela-se assim da maior importância.

Uma nova metodologia, baseada em Análise Multivariada de Dados, para identificação de amostras de solo e categorização, de acordo com o seu impacto na saúde humana, é aqui proposta. A utilização combinada de Análise em Componentes Principais (ACP) e Análise de Correspondências (AC) permitiu a identificação do grupo de elementos contaminantes que actuam na área de estudo. Uma vez identificado este grupo, foi possível, através de Análise de Correspondências, hierarquizar as amostras de solo de acordo com o seu potencial contaminante, estabelecido a priori com o recurso a valores guia de referência encontrados na literatura. Uma vez identificadas as amostras, estas podem ser projectadas permitindo o reconhecimento geográfico de zonas consideradas limpas, necessitadas de intervenção ou de reclamação.

Palavras chave: Áreas mineiras, Contaminação de solos, Análise em Componentes Principais, Análise de Correspondências

Introduction

Mining is one of the oldest activities in human civilization. Mining industry is a vital economic sector for many countries but it is also one of the most hazardous activities. Throughout ore processing several toxic wastes are produced and released into the surrounding environment causing pollution of air, drinking water, rivers and soils.

Mining activities cause several environmental impacts, as well as health impacts in the communities living near the mine site that may persist, even when the mine is abandoned (Ladou, 1995; Heyworth, 1995; USEPA, 1991; 1992).

A major environmental issue associated with mining and beneficiation wastes is the release of heavy metals and metalloids into the environment. Since sulphur is often present in the tailings where such wastes are dumped, exposure to the atmosphere in the presence of water leads to the production of acid mine drainage, a common type of pollution in mining areas that results from the oxidation of sulphide minerals leading to generation of free acidity and soluble metal species. The consequences of the contamination of the surrounding topsoil may become particularly worrisome when mining and ore treatment operations occur in populated areas.

The Panasqueira wolframite ore deposit is the biggest of Western Europe, which has been in operation from 1896 to the present date (with periods of higher and lower extraction rate, according to W prices in the international market). This long exploitation history gave rise to, among others, a huge tailing (7,000,000 m^3) and two mud dams (see Fig. 1), which are the source of pollution in the vicinity of the mining area. The Barroca Grande tailings dam is located nearby a small village, S. Francisco de Assis Village (urban fabric in Fig.1) with 692 inhabitants (source: 2001 INE Censos in www.ine.pt).

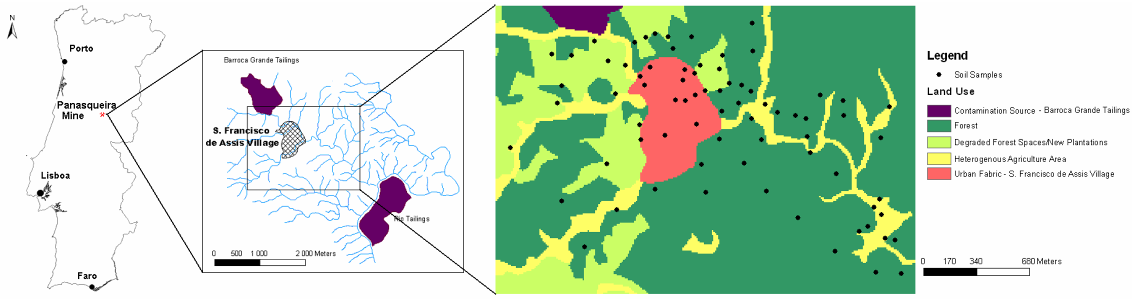

Fig. 1 – Panasqueira Mine location, including sample location and land use codes.

Ávila et. al (2008) showed that the effect of Panasqueira mining activity, which conduces to the release of metals from acid mine waters into the environment, is an actual and dynamic process. As a consequence, the downstream area of the tailings dam became a repository for heavy metals and metalloids, namely the chosen study area, which includes S. Francisco de Assis Village and its surroundings (Fig. 1).

From soils, plants are able to absorb fairly easy not only the nutrients needed for their development, but also some of the metals present. Therefore, the food chain can be straightforward compromised. This takes special importance in the study area, where agriculture and cattle breading is one of the principal economical activities, apart from the mine.

Geological Framework and Mining Activity

The Panasqueira ore deposit is a classical example of Sn-W hydrothermal mineralization associated to Hercynian plutonism. According to the paleogeographic and tectonic zonography established for the Hercynian Chain of the Hesperic massif (Lotze, 1945; Julivert et al., 1974), this deposit is included in the Central Iberian Zone. Folded metasediments of Cambrian to late Precambrian age showing low grade metamorphism outcrop in the area which is intruded by Hercynian granitoids. Near the contact, metasediments grade to spotted schists due to processes of contact metamorphism which can be observed in lithologies around the mine site (Conde et al., 1971; Bloot & de Wolf, 1953; Kelly & Rye, 1979). Outcrops of spotted schists were identified around the mine site, and are spatially associated with most of mineralization.

The mineral deposit is composed of a great number of sub-horizontal quartz veins rich in ferberite inside the metasediments. Wolframite, cassiterite and chalcopyrite are also ore minerals. A number of sulphides and carbonates fall in the category of principal accessory minerals (arsenopyrite, bismuthinite, galena, sphalerite, pyrrothite, marcassite and stannite) and other minerals occur in minor amounts (calcocite, covellite, cubanite, loellingite, molibdenite, pentlandite, stibnite and silver sulphosalts). The mineral paragenesis is complex showing repeated stages of mineral deposition. Four stages of mineralization were defined: 1) oxide-silicate phase; 2) main sulphide phase; 3) pyrrothite alteration phase; 4) late carbonate phase (Corrêa de Sá et al., 1999).

Panasqueira mining activity began in 1896 and it still, nowadays, in activity. The concession covers an area of more than 2000ha and the first underground drifts were opened at Cabeço do Pião (Rio), but mining activity, in this area, decreased when richer veins were discovered at Panasqueira mining district. The exploitation was extended to other areas, namely, Barroca Grande, Corga Seca, Panasqueira, Rebordões and Vale da Ermida (D'Orey, 1967; Corrêa de Sá et al., 1999).

The economic exploitation has been mainly focused on wolframite, cassiterite and chalcopyrite, these last two ores byproducts. In average the tout-venant contains 0.3% WO_3 and the final concentrates are recovered with 75% WO_3, 72% SnO_2 and 22%Cu together with significant amounts of Ag. The exploitation is focused at the present time in Barroca Grande area. This area is mountainous and rugged and is situated at 400 to 1000 metres above the sea level (Reis, 1971).

In Barroca Grande the existence of a huge tailing (7,000,000m^3) and two mud dams (deposition place of rejected materials from the ore dressing operations) must be emphasised. One of these is an old dam, although stabilized in geotechnical terms, whilst the other (smaller and disposed over the tailing) is being actually feed with steriles (some rich in sulphides).

Soil Sample Survey

The data collected in this case study has obtained in two different sampling locations. The first refers to soils downstream Barroca Grande tailing (75 samples, see Fig. 1 for sample location) collected in the vicinity of S. Francisco de Assis Village, in order to assess the contamination impact on those agricultural and residential soils due to mining activities. The second is referred to local geochemical background soils (20 samples), collected outside of mining influence, in Caselas area, aiming the local geochemical characterisation.

Soil samples were collected to the depth of 0-10cm with a plastic spade and the large majority of soils were residual and derived from metasediments substrate. After sampling, the soils were kept in polyethylene bags and brought to the laboratory. The samples were dried at 40 °C and sieved at 80 mesh, after this, they were crushed, homogenized and sieved, retaining the <200 mesh fraction for chemical analysis.

All samples have been localised by GPS and geo-referenced to UTM coordinates.

The finely and homogenised soil samples were submitted to multielemental analysis at LNEG-S. Mamede de Infesta accredited laboratory. For trace metal analysis a 0.5g split was leached in hot (95ºC) aqua regia (HCl-HNO_3-H_2O) for 1 hour. After dilution to 10ml with water, the solutions were analysed for 22 chemical elements by Conductive Plasma Emission Spectrometry and X-Ray Fluorescence (XRF) techniques. Among these, Ag, As, B, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Nb, Ni, P, Pb, Sb, V, Y and Zn (DPC) and Sn and W (XRF) were included. The detection limits were based on three times the standard deviation of a reagent blank that was analysed ten times. The accuracy and analytical precision were determined using analysis of reference materials (SO1, SO2, SO3, SO4, FER1, FER2, FER3, FER4 from Canadian Center of Mineral and Energy Technology; PACS-1 from NRS26 CNRC; 2711 from NIST) and duplicate samples in each analytical set. The results were within the 95% confidence limits of the recommended values given for this certified material. The relative standard deviation (RSD) was between 5 and 10%.

Methodology

The proposed methodology to evaluate soil contamination in the study area addresses jointly the harmful potential of a set of chemical elements prone to be toxic to the environment, as well as human by the uptake by food chain and direct exposure (including ingestion). For this end two techniques of Multivariate Analysis are used in cooperation, resulting in a two step process:

1. Results from soil chemical analysis are submitted to a PCA in order to identify groups of elements, which expert geological/environmental geochemical interpretation allows to distinguish from geological *vs.* anthropogenic origins.

   This technique main achievement is to identify patterns in large sets of data and expressing them in such way as to emphasize their similarities and differences. Since patterns in data can be hard to find in data of high dimension, where the luxury of graphical representation is not available, PCA is a powerful tool for analysing data. The other main advantage of PCA is that once data patterns are found, the set can by compressed, by reducing the number of dimensions, without much loss of information (Pereira & Sousa, 2002).

   PCA is a well established multivariate statistical method, developed by Hotteling (1933) for quantitative continuous variables that fit multigaussian distributions. In its initial formulation, as applied for the first time in geology by Imbrie and Purdy (1962),

   PCA has been highly used for this propose, by several authors, in soils contaminated by: organochlorine compounds (Škrbić & Durišić-Mladenović, 2007), metals (Barona & Romero, 1996, Borůvka et. al, 2005), *etc.*. However, these applications are very straightforward and PCA results are not interpreted in sample context, therefore being subject of other techniques in order to highlight their significance.

2. Once identified the contaminant group of elements associated with ore exploitation and processing, a complete disjunctive matrix of the data is built classifying each sample, for each element, as being Clean (above the average local background level), in need of Reclamation (above the guide level for agriculture soils) or in need of Intervention (if sample value is between mean local background and guide level). The referred complete disjunctive matrix is then submitted to a CA. Hence CA as the advantage of projecting variables and samples in the same factorial space (Greenacre, 1984) is possible to extract a hierarchy of samples according to their contamination level.

   CA is a multivariate factorial technique developed in the 1960's by the French mathematician Jean-Paul Benzécri for contingent tables used in the context of linguistics (Benzécri, 1973). The French School of Data Analysis ("The French Way" as Holmes (2008) puts it) has followed the track of the seminal Benzécri's approach, taking CA as the core of its research, and simple and multiple contingent tables as its basic data model. CA applies to variables (qualitative and quantitative), divided into modalities or categories, which are arranged under a matrix form, always composed by juxtaposed blocks of contingent tables. These blocks may be 'conventional' contingent tables, or they may represent variables encoded under the 'complete disjunctive' format for a set of individuals. The later is the most common format, where a matrix of *n* individuals *vs*. *q* qualitative variables (the categories of which are given by an indicator *j*) may be viewed as a series of *q* contingent tables (value 1 of the indicator for each table gives the number of co-occurrences of a given 'modality' *i* of the set of *n* individuals with a certain category *j* of the variable the table refers to).

   CA has been applied to a variety of domains that covers comprehensively 'hard' and 'soft' sciences, being the first application in geology carried out by Pages (1970).

Results and discussion

As previously mentioned, a two step soil sample campaign was carried out in the Panasqueira Mine vicinity. In the first step 75 samples were collected downstream Barroca Grande tailings, in the vicinity of S. Francisco de Assis Village, and on the second step, 20 soil samples were collected outside the influence of mining activity (Caselas area) in order to establish the local background. These samples were analysed for 22 chemical elements and summary statistic results are shown in Tables 1 and 2 for S. Francisco de Assis Village area and Caselas area, respectively. Comparing both tables there are some elements that stand out due to differences in its contents, in the soils of the study area and soils of local background. The maximum value of As is 24 times bigger in S. Francisco de Assis Village soils than in local background soils, the same occurs for other elements, such as: Cd (16.5 times), Co (16.9 times), Cu (14 times), Mn (37.5 times), Sn (15 times), W (42 times). Mean values between the two areas increased significantly for As, Cr, Cu, Mn, Mo, V, Y Sn and W.

Table 1 – Summary statistics for S. Francisco de Assis Village soil samples (concentrations in mg.kg^{-1}).

ID	Average	Mean	Min.	Max.	Variance	Variation Coefficient	Interquartile Range	Asymmetry Coefficient
Ag	1.03	1.00	1.00	3.00	0.05	0.22	0.00	8.66
As	117.63	82.00	9.00	**831.00**	17727.43	1.13	98.00	3.47
B	71.36	38.00	6.00	476.00	9456.45	1.36	36.00	2.82
Ba	289.07	292.00	149.00	414.00	3527.41	0.21	84.00	-0.28
Be	2.21	2.00	1.00	8.00	1.74	0.60	2.00	1.96
Cd	4.05	2.00	2.00	**33.00**	39.40	1.55	0.00	3.37
Co	18.64	10.00	4.50	**169.00**	632.76	1.35	5.00	4.05
Cr	205.53	198.00	131.00	326.00	1825.47	0.21	52.00	0.90
Cu	122.01	72.00	23.00	**791.00**	22665.01	1.23	71.00	3.05
Fe	3.98	3.90	2.40	7.00	0.35	0.15	0.60	1.57
Mn	1169.37	275.00	80.00	**20000.00**	8333404.80	2.47	446.00	4.83
Mo	2.21	2.00	2.00	11.00	1.71	0.59	0.00	6.15
Nb	9.69	10.00	2.00	15.00	6.62	0.27	3.00	-0.18
Ni	40.95	19.00	6.50	472.00	3452.69	1.43	22.00	5.81
P	857.35	550.00	227.00	4197.00	497851.58	0.82	715.00	2.26
Pb	23.91	16.00	8.00	78.00	224.55	0.63	14.00	1.56
Sb	8.63	10.00	6.00	19.00	5.24	0.27	4.00	0.84
V	102.44	101.00	59.00	139.00	244.06	0.15	22.00	0.21
Y	14.83	9.00	3.00	95.00	322.55	1.21	8.00	3.09
Zn	387.64	273.00	100.00	2709.00	165799.45	1.05	102.00	3.73
Sn	29.89	17.00	6.00	**167.00**	976.85	1.05	24.00	2.31
W	62.52	37.00	3.00	**592.00**	7605.58	1.39	55.00	3.82

Table 2 – Summary statistics for Caselas soil samples (concentrations in mg.kg^{-1}).

ID	Average	Mean	Min.	Max.	Variance	Variation Coefficient	Interquartile Range	Asymmetry Coefficient
Ag	1.00	1.00	1.00	1.00	0.00	0.00	0.00	N/A
As	13.60	9.00	9.00	**34.00**	70.78	0.62	13.00	1.47
B	25.05	26.00	8.00	47.00	69.31	0.33	12.00	0.56
Ba	337.65	337.00	233.00	574.00	4774.66	0.20	59.00	2.05
Be	2.15	2.00	1.00	3.00	0.34	0.27	1.00	0.00
Cd	2.00	2.00	2.00	**2.00**	0.00	0.00	0.00	N/A
Co	10.00	10.00	10.00	**10.00**	0.00	0.00	0.00	N/A
Cr	148.40	149.00	116.00	209.00	380.67	0.13	13.00	1.52
Cu	36.70	38.00	17.00	**57.00**	112.64	0.29	18.00	0.17
Fe	4.54	4.40	3.70	5.60	0.30	0.12	0.70	0.41
Mn	297.35	311.00	111.00	**534.00**	14985.71	0.41	148.00	0.37
Mo	4.00	4.00	4.00	4.00	0.00	0.00	0.00	N/A
Nb	12.25	12.00	9.00	18.00	5.78	0.20	5.00	0.89
Ni	19.70	18.50	18.50	39.00	20.69	0.23	0.50	4.45
P	558.15	500.00	330.00	1016.00	34248.87	0.33	225.00	1.35
Pb	21.80	16.00	16.00	57.00	127.43	0.52	17.00	2.02
Sb	10.00	10.00	10.00	10.00	0.00	0.00	0.00	N/A
V	122.30	124.00	98.00	143.00	142.85	0.10	13.00	-0.56
Y	4.85	5.00	3.00	7.00	1.29	0.23	2.00	0.08
Zn	258.30	264.00	210.00	299.00	635.38	0.10	36.00	-0.29
Sn	6.15	6.00	4.00	**11.00**	2.87	0.28	2.00	1.18
W	5.55	5.00	2.00	**14.00**	7.52	0.49	3.00	1.46

A matrix of 95 (samples) x 22 chemical elements was then submitted to a Principal Component Analysis, which explains 84.8% of the total variance in the first six factors. The first 2 factorial planes (Fig. 2) account for 67.1% of total variance and explain all variables with exception of P, associated with the negative semi-axis 4 (-0.6166, loading value); and Mo, associated with the negative semi-axis 6 (-0.5810, loading value).

To the first component, F1, which explains 43.4% (see Table 3) of the total variance, is associated Group A composed by Cu, Y, Co, Mn, Cd, As, Zn, Ni, Be, W, Sn and Pb. This group is a typical association of elements representative of the original paragenesis (the most common minerals in addiction to quartz are: wolframite, pyite, pyrrhotite, arsenopyrite, chalcopyrite, cassiterite, beryl, mica and fluorite) which still maintain a close relationship in the secondary environment.

To the second component, F2, which explains 14.2% of the total variance, are associated two groups. Group B, composed by V, Fe, Ba and Nb, is associated to the positive semi-axis, while Group C, composed by Cr, is associated with the negative semi-axis. These groups can be associated with the dominant lithological unit (brown argillaceous schists and dark grey siliceous shicts intebebded with rare greywackes).

Group D, composed by the association Sb, Ag and B, is strongly associated with F3, which explains 9.5% of total variance. This component separates the main sulphide mineral phases.

Table 3 – Results of PCA.

Variables	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**
Ag	0.4714	-0.0710	**0.6637**	0.0841	-0.4658	0.1455
As	**0.8986**	-0.1088	0.1509	-0.0071	-0.1493	0.0896
B	0.3294	-0.1936	**0.5234**	-0.4006	0.5588	-0.2313
Ba	0.1103	**0.6658**	-0.0520	-0.4612	-0.0310	0.1838
Be	**0.8324**	0.2801	0.1806	-0.1858	0.1701	-0.0846
Cd	**0.9142**	0.1136	-0.1398	0.2349	0.0457	0.0142
Co	**0.9440**	0.1214	-0.1753	0.1999	0.0671	0.0027
Cr	0.1083	**-0.6484**	-0.0861	-0.0371	0.1025	0.5152
Cu	**0.9713**	-0.0156	0.0202	0.0869	-0.0676	0.0283
Fe	0.1024	**0.8024**	0.1548	-0.0872	-0.0539	0.2677
Mn	**0.9183**	0.1323	-0.2182	0.2080	0.0968	-0.0091
Mo	-0.2243	0.3595	0.1298	0.4380	-0.1575	**-0.5810**
Nb	-0.2789	**0.6432**	0.1468	0.0635	0.2050	0.0935
Ni	**0.8633**	0.1412	-0.2929	0.2010	0.1797	-0.0075
P	0.4069	0.0545	-0.2484	**-0.6166**	-0.4525	-0.2332
Pb	**0.5301**	0.1112	-0.2017	-0.3424	-0.4275	-0.1094
Sb	-0.1664	0.0710	**0.7666**	0.3206	-0.1900	0.0493
Sn	**0.6275**	-0.1779	0.4248	-0.3575	0.3681	-0.1606
V	-0.2567	**0.8649**	0.1317	-0.0192	0.0966	0.1788
Y	**0.9711**	-0.0130	0.0228	0.0954	-0.0675	0.0281
W	**0.8012**	-0.2336	0.3611	0.0165	-0.2034	0.0624
Zn	**0.8788**	0.1753	-0.2090	0.2048	0.1884	-0.0090
Eigenvalues	9.5438	3.1342	2.0890	1.5858	1.3644	0.9396
% Total Variance	43.4	14.24	9.5	7.2	6.2	4.38
% Cumulative Variance	43.4	57.6	67.1	74.3	80.5	84.8

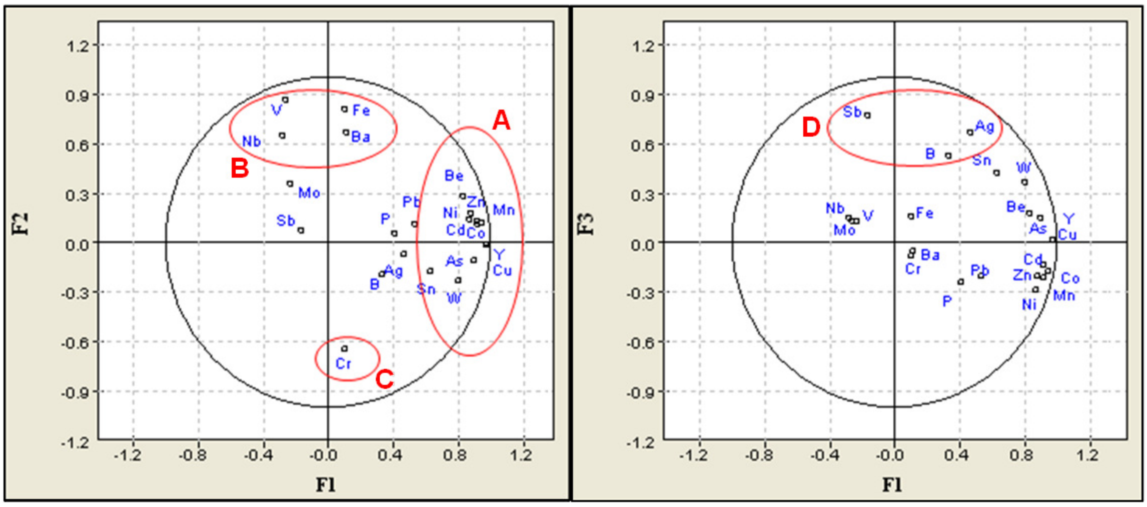

Fig. 2 – Graphical representation of the first two factorial planes of PCA:

Once identified the contaminant group of elements – Group A – it is possible to establish three categories within each variable (chemical element), according to a set of rules. If a sample value is below the average value of local background (Caselas soils) the sample is considered clean (a C will appear after chemical symbol). If the sample is above literature guideline values for agriculture purposes is considered to be in need of remediation/reclamation (an R will appear after chemical symbol). In the other hand, if sample value is between average local background and guideline value is considered to be in need of intervention, i.e., in need of further investigation (an I will appear after chemical symbol).

In what guideline values for agriculture soils in Portugal are concerned, Ferreira (2004) established, for a set of chemical elements, its respective guide values, specifically for Group A: As=30mg.kg^{-1}, Co=40mg.kg^{-1}, Cu=100mg.kg^{-1}, Ni=75mg.kg^{-1}, Zn=300mg.kg^{-1}. These values were used as the inferior limit of a soil in need of reclamation. For Be (4mg.kg^{-1}), Cd (4mg.kg^{-1}) and Pb (70mg.kg^{-1}) the limits used were the ones established by the CCME (1999) guidelines for agriculture soils, once guideline values for these elements have not been established for Portuguese soils. Neither Ferreira (2004) nor CCME (1999) present guide values for Y, Sn and W, for these elements only two categories were created, inferior or superior average local background, the last been recognised as being in need of intervention.

Based on the categories established for each variable (chemical element) a complete disjunctive matrix was built, according to the model presented in Fig. 3. The referred matrix constitutes the input matrix for the Correspondence Analysis (CA).

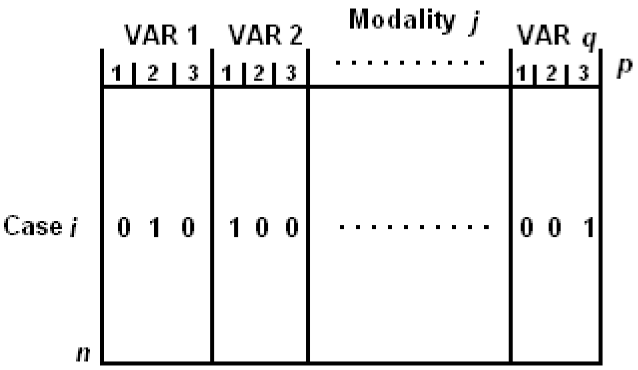

Fig. 3 – Complete disjunctive format.

The first factorial plane of CA explains approximately 44% of total inertia of the data, and its graphical representation can be observed in Fig. 4.

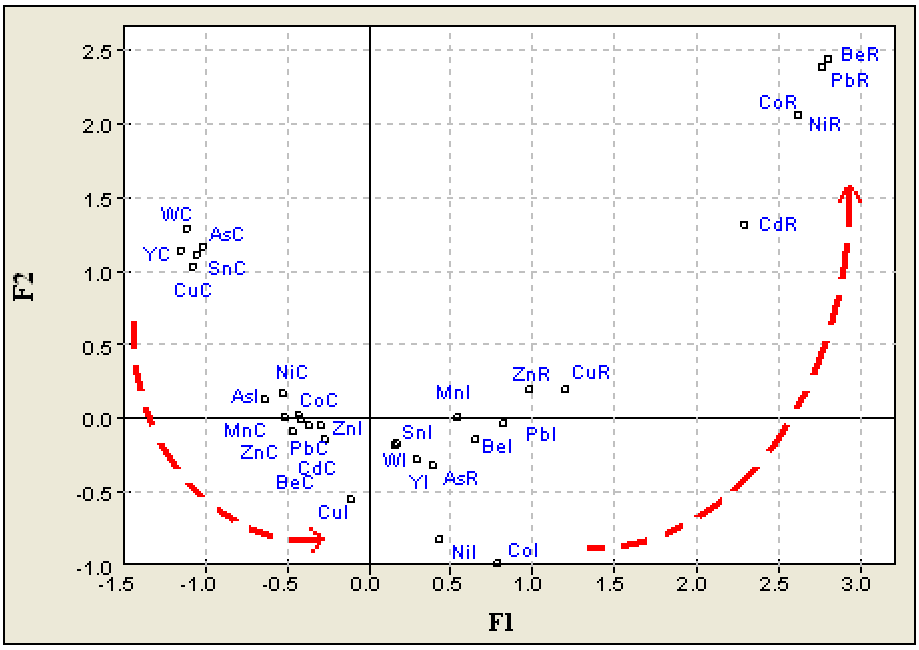

Fig. 4 – Graphical representation of modalities projection into the first factorial plane of CA.

All variables can be considered ordinal variables, since there is an hierarchy present, from the negative semi-axis where the modalities with smaller values are projected (considered clean), to the positive semi-axis where the modalities with the higher values are projected (considered to be in need of reclamation), according to the limits previously established.

As it is possible to observe in Fig. 4, the modalities are disposed in a parabola shape, showing a clear distribution along the first axis. Hence, modalities are ordinate in an ascending way along this axis, from clean to in need of reclamation passing trough in need of intervention, asymptotically this axis can be considered as function index of the sample contamination gradient.

CA has the advantage of projecting modalities and samples in the same factorial plane. This is a very important feature, once it allows a simultaneous interpretation. In Fig. 5 is presented the projection of the samples in the same factorial plane of Fig. 4. Samples show the same distribution of modalities along F1. This way is possible to identify the samples associated with each one of the categories.

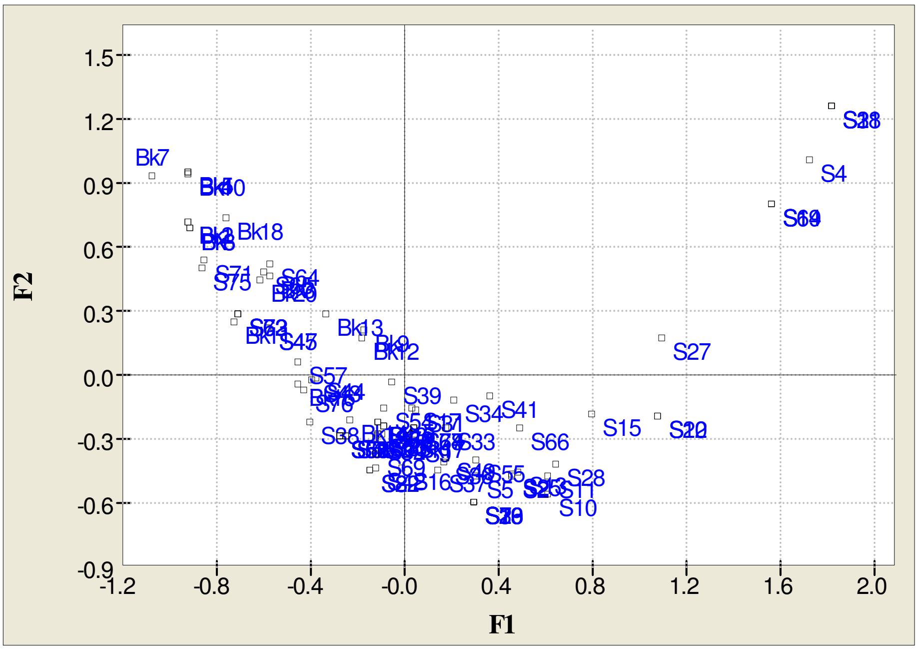

Fig. 5 – Graphical representation of samples projection into the first factorial plane of CA.

Once spitted the sample set according to their harmful potential effects is possible to map it, as shown in Fig. 6.

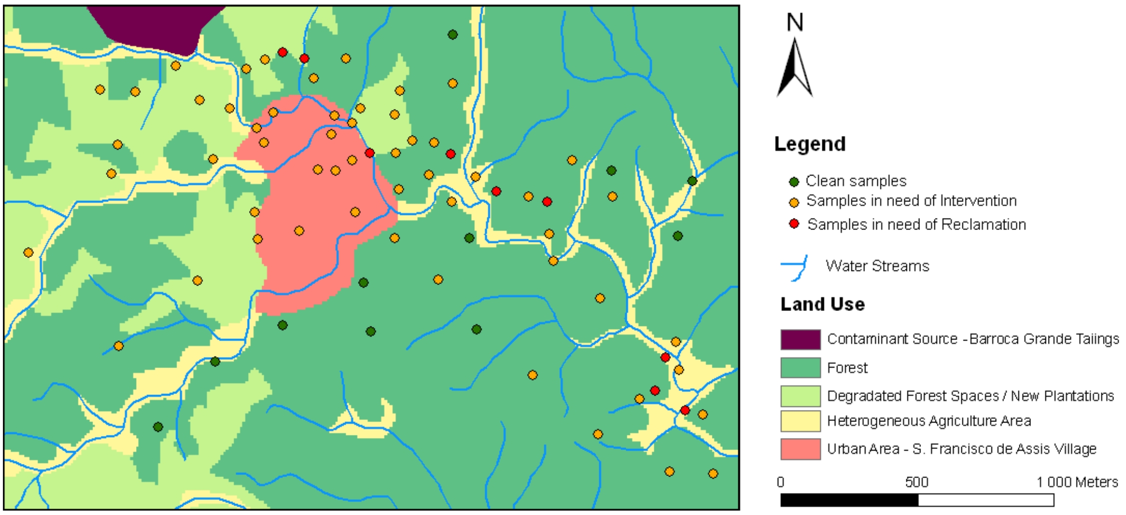

Fig. 6 – Sample mapping according to their harmful potential and land use.

In a region where agriculture and cattle breading is, after mining, the principal economical activity is imperative to cross-referencing the contaminant potential and harmful effect of soils with land use. Fig. 6 reveals that samples in need of intervention and reclamation are disposed preferentially in urban and agriculture areas, reflecting the significance of further studies in this community, not only in what soil geochemistry is concerned (establish a new soil campaign increasing the number of samples, perform bioavailability and bioaccessibility studies in the most pernicious elements in what human health is concerned) but also biomarkers studies in the exposed population.

Conclusions

The mining exploitation and ore processing at Pananqueira Mine produces a large amount of residues rich in heavy metals and As, which are the main source of pollution in the surrounding environment, namely in S. Francisco de Assis Village soils.

In practical terms is not possible to quantify monetarily land use, especially in a community highly dependent on land for one of their principal economical activities, and the harmfulness to humans cannot be put in the same scale as to ecosystems, resulting in the fact that a remediation cost-benefit analysis is not suitable in this scenario. However the practical results of this study allows to select areas where an eventual remediation procedure may be foreseen; giving priority to areas where samples are classified as in need of reclamation when geographical positioned in agriculture or urban areas.

The proposed methodology, combining a two step factorial analysis proved to be a useful tool for this proposes. PCA has the robustness required for the identification of group of chemical elements, which combined with expert geological/environmental geochemical knowledge allowed its interpretation. CA has the discriminate power for variable categorisation and sample identification.

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